National Bureau of Standards

TECHNICAL NEWS BULLETIN

VOLUME 33 JUNE 1949 NUMBER 6

S.93 S6T1

Technology

PUBLIC LIBRARY
JUN 1949
DETROIT

NBS Liquid Oxygen Converter

A liquid oxygen converter [1] having significant advantages for use in high-altitude flight has been developed by W. A. Wildhack and associates of the National Bureau of Standards with the cooperation of the Bureau of Aeronautics, Department of the Navy. The converter is fully automatic, requiring no electric or other source of power. Its compactness and greatly reduced weight represent a decided advance over gaseous equipment now used to supply breathing oxygen in aircraft. Other desirable features include sturdiness, simplicity of design and operation, rapid attainment of operating pressure, economy of oxygen, and delivery of warm gas.

In addition to its use in aviation, gaseous oxygen has many other applications in modern science and technology; in the welding and cutting of metals, in manufacturing and refining processes, in the operation of certain types of engines and rockets, and in medical treatment. For all of these uses, both weight and bulk of containers can be greatly reduced if the oxygen is stored in liquid form. Liquid oxygen is five times as dense as oxygen gas under 2,000 pounds per square inch, the pressure to which most standard oxygen tanks are filled; and as the liquid oxygen may be stored and used at relatively low pressures, the container and fittings for liquid use weigh considerably less than the containers for the same weight of gas, in some cases as little as one-fifth. When oxygen is carried as a gas on aircraft, the cylinders must be recharged both in and out of the plane by connection to stationary cylinders, and the storage cylinders have to be shipped, recharged, and reshipped. For military use, the returning of heavy, empty gas cylinders from advanced bases for refilling has been a serious logistics problem.

Although the advantages of supplying oxygen in liquid form have long been recognized, its widespread use has been prevented by the disadvantage of continuous evaporation losses during storage and the necessity of controlling the build-up of pressure to that required for operation (about 50 pounds per square inch for oxygen breathing regulators). The program for the development of liquid oxygen equipment undertaken by this Bureau resulted in the design of a liquid oxygen converter permitting rapid attainment of any preassigned value of pressure. However, evaporation losses during storage are still something of a limitation, especially with small containers.

The NBS Liquid Oxygen Converter consists of a standard 25-liter metal Dewar flask modified by the addition of a bottom drain, together with two coils, one for build-up of pressure and one for warming the gas as it is delivered. After it is filled with liquid oxygen, the flask may be sealed off from the atmosphere. When oxygen gas pressure is to be built up, a valve is opened, allowing liquid to flow through a drain tube and liquid trap at the bottom of the flask and into the build-up coil, where it is evaporated and warmed by the atmosphere. The warm gas rises through the coil

[1] Based on a paper by W. A. Wildhack and D. S. Goalwin of the National Bureau of Standards, presented at the winter meeting of the Institute of the Aeronautical Sciences in New York. The paper describing this development of W. A. Wildhack and associates, including J. M. Davis, Murray Eden, and C. Eve, was released by the Bureau of Aeronautics, Department of the Navy, under whose sponsorship this work was done at this Bureau.

837070—49

by thermal convection until it enters the top of the flask, where it mixes with the gas above the liquid. Here some of the gas condenses on the liquid surface, but the condensed gas is immediately replaced by freshly warmed gas and the cycle continues, gas pressure rising quickly. Once pressure is established, gas may be withdrawn by forcing liquid through the bottom drain into the withdrawal coil, where it is evaporated and warmed by the atmosphere as it passes to the outlet mechanism. Excessive rise in pressure is prevented by the closing of an automatic bellows-type valve in the build-up coil, which stops the flow of additional gas to the top of the flask. At higher pressures another pressure-actuated valve—the "economizer"—vents gas directly from the top of the converter to the delivery coil. When this circuit is open, any withdrawal of gas drops the pressure quickly to operating values. Two pressure relief valves are also provided, one in the build-up tube and the other in the delivery line.

The fact that it is not necessary to heat the entire mass of liquid to raise the pressure constitutes an important difference between this and earlier types of liquid oxygen converters. The rapid decrease in density of the liquid with increasing temperature makes possible a relatively warm surface layer in the liquid, as very little heat is lost from this layer to the rest of the liquid by convection. Thus, the heat transferred to the gas as it passes through the build-up coil is largely retained in the space above the liquid in the container, and a rapid increase in pressure results.

The total converter unit is 25 inches high and 18 inches in diameter. It weighs 60 pounds and holds 62 pounds of oxygen, enough for 10 men for 10 hours. To supply this quantity of oxygen from gas cylinders at 1,800 pounds per square inch would require 21 tanks of 514 cubic inches each, which would weigh a total of 350 pounds when empty. For flows up to 150 liters per minute (5 cubic feet per minute), gas is delivered within 5° C of atmospheric temperature. Flow rates over 10 times as great may be obtained, but at these larger flows the delivered gas is colder.

The NBS liquid oxygen converter (right) represents a decided reduction in volume and weight of equipment used to store breathing oxygen in aircraft. The new 25-liter device effectively replaces 22 514-cubic-inch gas cylinders (left). The liter flask (center) contains in liquid form the same amount of oxygen as does a single gas cylinder.

Pressure may be built up, when the container is full, from 0 to 65 pounds per square inch in 10 seconds. The flask is somewhat stronger than the standard Dewar flask and will withstand internal pressures of 200 pounds per square inch. Pressure once achieved is quite stable, and although it drops with vigorous shaking, recovery is almost instantaneous. The depth of the liquid in the container is measured by a differential bellows-type manometer connected between the bottom drain and the top of the neck of the Dewar. To permit the converter to operate even in an inverted position, a gravity circuit is provided, consisting of a line from the top of the neck of the Dewar to the bottom of the delivery coil. It contains a gravity-controlled valve that opens only when the apparatus is inverted.

The converter has successfully withstood tests at the National Bureau of Standards and other Government laboratories under conditions of severe vibration (3,000 cycles per minute), rapid acceleration (nine times the

TECHNICAL NEWS BULLETIN

U. S. DEPARTMENT OF COMMERCE
CHARLES SAWYER, *Secretary*
NATIONAL BUREAU OF STANDARDS
E. U. Condon, *Director*

JUNE 1949 Issued Monthly Vol. 33, No. 6

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. Subscription price $1.00 a year; single copy, 10 cents. The printing of this publication has been approved by the Director of the Bureau of the Budget, February 14, 1947.

Contents

	Page
NBS liquid oxygen converter	65
Nature of adhesion	67
Properties of lightweight aggregate concretes	69
Research underlying a national uniform plumbing code	72
New uses for magnetic fluids	74
NBS publications	76

acceleration of gravity), severe cold (−40° C), and severe heat (75° C). Performance at tilts up to 45° was not materially different from that observed in the erect position. When the apparatus was inverted, pressure rose somewhat more rapidly because of the shorter heat path from the atmosphere to the liquid in the neck, but in 5-minute runs the pressure rise was not generally sufficient to open the relief valve. Converters built on the NBS design by commercial manufacturers have operated satisfactorily in flight tests carried out by the Air Force and the Navy at altitudes up to 40,000 feet.

In reliability and safety the new converter compares favorably with high-pressure gaseous oxygen systems. Wide variation is possible in container capacity, and in delivery flow, temperature, and pressure specifications. Thus, although designed specifically for aviation use, the device may be adapted with minor modifications to industrial and medical applications.

Nature of Adhesion

In recent years the nature of adhesion has become the subject of a fundamental research program at the National Bureau of Standards. This project, sponsored by various Government agencies, was initiated in 1945 with a survey of the literature on adhesives and the theory of adhesion.[2] Because of the dearth of comprehensive data in this field, the Bureau extended this program to include investigations of the adhesive properties of a wide variety of adhesives and adherends. Results of this research, conducted by N. J. De Lollis of the Bureau's organic plastics laboratory, have led to a better understanding of the specific attraction between various types of adhesives and adherends and hence more complete knowledge on the nature of adhesion.[3]

Prior experimental work on adhesives has been concerned largely with the development and use of products for specific industrial purposes. For example, the aircraft industry has employed adhesives extensively in airplane assemblage. Current interest in sandwich construction also serves to emphasize the increasing importance of adhesives in new types of airplanes. The small-boat industry has made wide use of the more recently developed waterproof adhesives, not only in making plywood boats but also in forming boats under low pressure from glass cloth laminates.

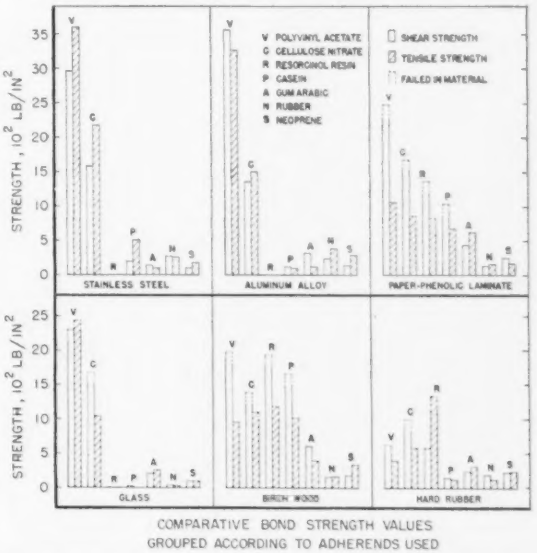
Among the adhesives included in the Bureau's investigation were cellulose nitrate, polyvinyl acetate, resorcinol-formaldehyde, casein, gum arabic, natural rubber, and neoprene. These were modified as little as possible, so that the relation between adhesive and adherend would be due to the simplest possible combination. The adherends chosen, aluminum alloy, stainless steel, paper phenolic laminate, plate glass, birch wood, and hard rubber, are a fair sampling of the materials of industry, have a wide range of elastic moduli—the property best correlated with bond shear strength—and their chemical and physical structure make possible a variety of adhesive bonds.

Test specimens were prepared by using each adhesive in turn with each adherend; only one adherend was used in any one specimen. The proper treatment of the adherend surfaces was found to be of primary importance since, when exposed to ordinary atmospheric conditions, they usually pick up impurities in the form of oxide, dust, or oil films. If dirt or impurities are present, close contact between the adhesive and the base adherend surface is prevented, and the best adhesive action is not obtained.

Prior to preparation of metal-adherend specimens, the surfaces were cleaned of oil and grease by rinsing in volatile organic solvents followed by pickling in acid to remove any loose oxide film. The glass surfaces were prepared by soaking in a sodium dichromate-sulfuric acid solution, then rinsing with water. Birch wood, phenolic laminate, and hard rubber were sanded with No. 00 sandpaper.

Specific bonding conditions for the test assemblies were developed for each adhesive, depending on the chemical and physical nature of the adherend. These conditions ranged from 3 pounds per square inch pressure, for a gum arabic adhesive, dried 20 hours at 25° C, to 150 to 200 pounds per square inch pressure, for a rubber adhesive cured 7 hours at 140° C.

The specimens, after conditioning for a minimum period of 7 days at a temperature of 25° C and 50-percent relative humidity, were tested at the same temperature



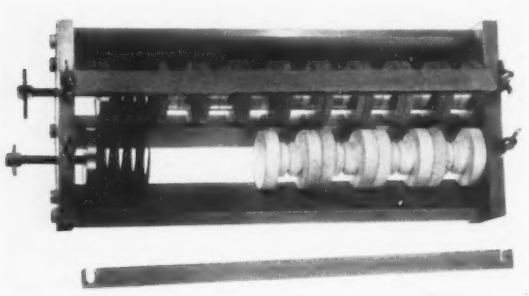
Bond strengths developed by various adhesives are compared in the NBS study of adhesive-adherend systems.

[2] NACA Technical Note No. 989, Survey of adhesives and adhesion, R. C. Rinker and G. M. Kline, National Bureau of Standards.

[3] For further technical details see NACA Technical Note No. 1863, Comparative strengths of some adhesive-adherend systems, by N. J. De Lollis, Nancy Rucker, and J. E. Wier.

and humidity for shear, tension, impact, and fatigue properties. All combinations were subjected to the shear and tensile tests. The impact test provided a means for studying differences between a brittle and a rubbery bond, and the fatigue test was utilized to investigate how a thermosetting and a thermoplastic bond differ.

Except for glass specimens bonded with polyvinyl acetate and cellulose nitrate, a tensile shear load, applied to a double-lap-joint specimen, was used in every case for the shear-strength determinations. Glass proved too



Special clamping frames were designed for preparation of tensile-adhesion specimens. For each adhesive it was necessary to develop specific bonding conditions, depending on the chemical and physical nature of the adherend.

brittle when subjected to tensile-shear loads of more than 200 to 300 pounds per square inch. However, compression-shear specimens were able to withstand loads of more than 2,500 pounds per square inch.

Tensile-adhesion values were obtained by using dumbbell-shaped specimens [4] with contact areas of 1 square inch, ½ square inch, and ¼ square inch. When the adherends were much weaker than the adhesives, dumbbell-shaped specimens with the smaller contact areas were prepared in order that the specimens would fail at or near the bond interface.

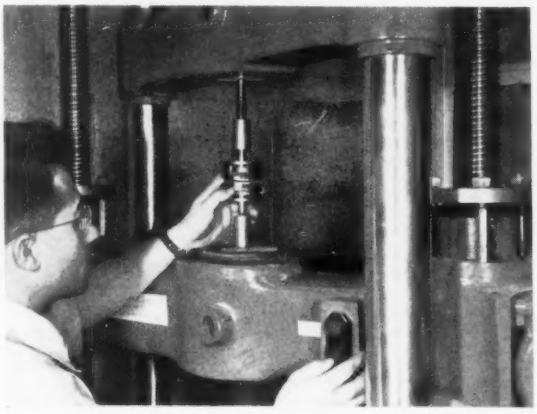
The rate of loading in both the shear and tensile tests was adjusted within the limits of 200 to 1,000 pounds per minute, so that failure of the bond would occur after approximately 3 minutes. Thus the time of fatigue would be about the same for all specimens.

The fatigue properties of thermoplastic and thermosetting resins were studied by using a double-lap tensile-shear specimen with a ½-inch overlap. By varying the width of such specimens—to which a 50- or 100-pound weight was attached—a range of shear stresses from 200 to 1,300 pounds was obtained. Impact-resisting properties of rubbery and brittle cements were compared, by using single-lap specimens of both aluminum alloy and wood. These specimens were broken with a pendulum impact machine of 2 foot-pound capacity.

An evaluation of the data gathered in this project was obtained by tabulating the results with respect to two fundamental properties of the materials involved. These are dielectric constant and modulus of elasticity, the former an electrical and the latter a mechanical property. The dielectric constant was considered to be of possible importance, since most modern theories attempt to explain adhesion on the basis of electrical forces.

The tabulations tended to show greater correlation with the moduli of elasticity than with the dielectric constants. When a high-modulus adhesive was used with a high-modulus adherend, the bond strength was negligible. When a low-modulus material was used, its strength became the limiting factor in the strength of the bonded assembly. The best results were obtained when medium-modulus materials were used with each other or with high-modulus materials. For instance, resorcinol-formaldehyde, a high-modulus adhesive, provided no adhesive action with glass and metals, both of which are high-modulus adherends. However, it gave good results with wood, a medium-modulus adherend. Polyvinyl acetate, a medium-modulus adhesive, gave consistently good values with all the adherends.

Results of these investigations indicate that there are many variables involved in adhesion and that the breaking stress of a specimen is not always a measure of the adhesive-adherend bond strength. Instead it may be a measure of the cohesive strength of the adhesive or the adherend. A break at the adhesive-adherend interface,



Tensile-adhesion strengths of adhesive-adherend combinations were determined with dumbbell-shaped specimens and self-alining grips in a universal hydraulic testing machine. To insure that the fatigue of all specimens would be the same, the rate of loading was adjusted so that failure of the bond would occur after approximately 3 minutes.

for example, may be attributed not so much to lack of adhesion as to the overshadowing effects of strains produced by temperature differentials or by adhesive-layer shrinkage resulting from solvent evaporation.

Chemical action between the adhesive and the adherend may also result in loss of strength in the bond assembly. This may be due to the weakening of the adhesive or adherend because of the chemical action, or it may be due to the formation of a weak chemical layer at the bond interface.

[4] ASTM Committee D-14 on Adhesives: Tentative method of test for tensile properties of adhesives (Aug. 28, 1944).

As already mentioned, most present-day theories relate adhesion to electrical forces. Such forces, which may arise from hydroxyl, acetyl, nitrate, and other polar groups, may be important in pure adhesion, but they tend to become secondary in an actual bonded assembly where other variables are of prime importance. The electrical forces, nevertheless, are probably the basic forces of adhesion and are always present.

The problem therefore becomes one for which a means must be found to modify the other variables in order to make the fullest use of the basic attractive forces. For a more thorough study of adhesion, it is necessary to separate these variables, whether electrical or mechanical, and to study each one separately. The program at this Bureau is being planned with this in mind. At present a study of the heats of wetting properties is under way in an effort to evaluate the importance of various polar groups.

Properties of Lightweight Aggregate Concretes

Since the First World War, a wide variety of lightweight materials, both natural and processed, have been introduced and marketed as concrete aggregate. To obtain the engineering data needed for studies of the manner and extent to which lightweight aggregate concrete may be useful in the present housing program, an investigation was initiated jointly by the National Bureau of Standards and the U. S. Bureau of Reclamation, at the request of and with the financial assistance of the Housing and Home Finance Agency. Results of the research at this Bureau show that it is possible to make concretes of low-cement content with excellent workability, sufficient strength, and adequate heat insulation for certain applications in building construction.

During both world wars, lightweight aggregate concretes were used to a limited extent as substitutes for the materials commonly employed in the construction of barges and ships. Lightweight materials also have been found advantageous for the floor construction of some of the world's greatest bridges, and as both the fireproofing and the structural concrete in multi-story buildings resting on foundation materials of low-bearing capacity. However, the available supply of cinders and the expanded clay, shale, and blast furnace slag aggregates has been absorbed by producers of concrete building blocks. The use of the lighter aggregates has been limited principally to concrete for thermal insulation and for roof and floor fillers.

For some structures, the possibilities of economies resulting from a reduction in the weight of the concrete are apparent, notably for tall buildings constructed on soft foundations and for structures designed to resist strong earthquake forces. The advantages of lightness for materials used in the construction of housing structures are not so obvious, except that tilt-up construction might be simplified and important savings effected in the cost of transporting and erecting precast panels. Data provided by the recent investigations will aid in determining the potentialities of lightweight aggregate concretes in housing structures.

The studies at this Bureau were limited to one sample of each type of aggregate material, except for three samples of slag. The investigation was also restricted to plastic concrete as distinguished from pressed or tamped concrete as used in concrete masonry units.

Eleven lightweight aggregates (described in table 1) were included in the Bureau's study. These consisted of exfoliated vermiculite; two processed materials, sintered diatomite and fly ash; expanded perlite, blast-furnace slags, shales, slates, and clays; and one natural material, pumice. The samples of expanded slate and expanded clay were furnished for experimental

TABLE 1.—*Description of lightweight aggregates tested*

Aggregate	Description
Exfoliated vermiculite	A type of mica that has been expanded by the action of heat. The particles were soft and fragile and had flaky laminated structures. Color, brown to buff with metallic luster on laminated surfaces.
Sintered diatomite	A processed diatomite that had soft chalky particles. Color, light tan to light pink.
Perlite	An expanded perlite composed of frothy particles that were fragile and irregular in shape. Color, white.
Expanded slag No. 1	A slag expanded in the pit process. The particles were irregular, the relatively large cell structure creating a rough surface texture. Color, light to dark gray.
Expanded slag No. 2	A slag expanded from runner. Similar in surface characteristics to expanded slag No. 1. Color, almost black to light gray with occasional cream-colored particles.
Expanded slag No. 3	A machine-processed expanded slag. Similar in appearance to expanded slag No. 2. Color uniformly cream colored with only an occasional gray particle.
Sintered fly ash	A processed material resulting from the combustion of powdered fuel in steam power plants. Similar in appearance to ordinary cinders, extremely rough and irregular in shape. Sample contained numerous black glass particles. Color, dark brown to black.
Pumice	A natural lightweight material of volcanic origin. The particles contained uniformly small cell structures. The surfaces were fairly soft and granular in texture. Color, off white.
Expanded shale	A shale expanded by heat. The particles were angular but not sharp or rough. The internal structure was smaller, with more uniformly sized cells than the expanded slags. Color, uniformly medium gray.
Expanded slate	A slate expanded by heat with fairly well-rounded and reasonably smooth particles of laminar structures. Material produced experimentally by the Bureau of Mines, College Park Station. Color, buff to brown.
Expanded clay	A clay expanded by heat with well-rounded and fairly smooth surface and uniformly small cell structure. Color, tan to gray. Material produced experimentally by the Bureau of Mines, College Park Station.

purposes by the Bureau of Mines, College Park Station; the other nine were commercial products. For comparison, Potomac River sand and gravel were also included and treated in the same manner as the lightweight aggregates.

The investigation at the Bureau consisted of two parts: (1) Tests concerned with the properties of the aggregate themselves and (2) tests to determine the properties of concrete containing various proportions of cement and aggregates (table 2). Because of the angular character of the individual particles and their peculiar absorptive properties, techniques for testing, proportioning, and mixing the aggregates differed somewhat from those used for the ordinary natural dense-aggregate mixtures.

TABLE 2. *Types of tests for aggregates and concretes*

Aggregate	Concrete
Sieve analyses	Compressive strength.
Specific gravity	Flexural strength.
Absorption	Shrinkage.
Unit weight	Absorption.
Grading (mechanical analysis).	Elastic modulus—static, dynamic.
Crushing strength	Resistance to freezing and thawing.
	Thermal conductivity.

The proportions of cement to aggregate were such as to produce concrete mixtures from each aggregate containing nominally three, five, seven, and nine bags of cement per cubic yard of concrete. The consistency of each batch of concrete was measured by means of the standard slump test. Test specimens were prepared in triplicate, except for the compressive-strength and the thermal-conductivity tests. Five like specimens were used for the former and one for the latter.

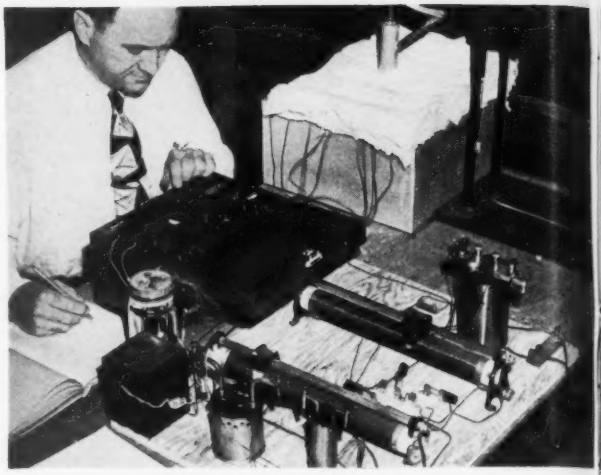
Air entrainment was found to assist materially in promoting workability of the concretes made from lightweight aggregates. Such entrainment of air enabled the cement and water to remain in suspension throughout the mass of the concrete, whereas without the air the ingredients would have segregated. The entrained air also acted as a lubricant, allowing the concretes to flow readily into the forms with a minimum amount of puddling or vibrating. Though it had a small effect in reducing the weight of concrete, the entrained air was greatly beneficial in increasing resistance to disintegration by freezing and thawing.

Physical and Mechanical Properties

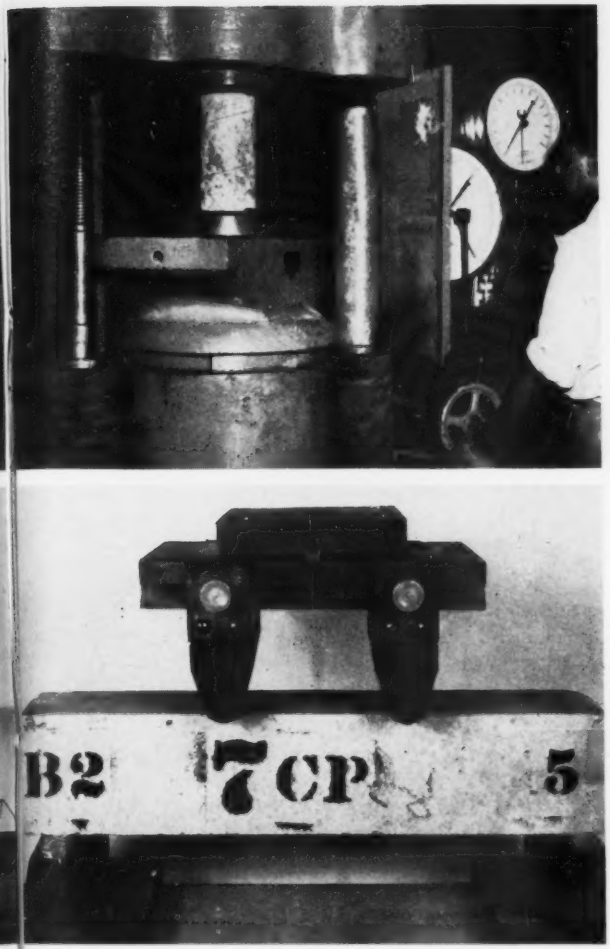
The lightweight concretes investigated ranged from one-fifth to three-fourths of the weight of ordinary sand-and-gravel concrete. The density, which varied with portland-cement content, ranged from less than 50 pounds per cubic foot (vermiculite and perlite) to 110 pounds per cubic foot. Sand-and-gravel concrete weighs about 145 pounds per cubic foot. The range between 70 and 110 pounds per cubic foot included the pumice, slags, sintered fly ash, and expanded clay, shale, and slate aggregate concretes.

The compressive strength of air-dried concretes, tested at 28 days, was markedly affected by the amount of cement in the mix. Considering 5-sack-per-cubic-yard proportions, compressive strengths of the concretes ranged from less than 300 pounds per square inch for those with vermiculite and perlite aggregate to approximately 5,000 pounds per square inch for that with sand-and-gravel aggregate. The majority of the lightweight concretes gave compressive strengths between 700 and 2,500 pounds per square inch. The 7-sack mixes were materially stronger, ranging up to 6,000 pounds per square inch for expanded shale.

As might be expected, the porosity of the concrete was found to increase as weight decreases, ranging from 50 percent of water absorbed by volume for a 3-sack mix of vermiculite concrete (28 pounds per cubic foot) to 7 percent for a 9-sack expanded clay (100 pounds per cubic foot). The corresponding absorptions by weight were approximately 118 and 4 percent, respectively. With very few exceptions, porosity increased with de-



Concretes prepared from a variety of natural and processed lightweight laboratories to determine their suitability for certain housing applications. are heat conductivity (upper left), structural soundness after freezing a (upper right), and transverse strength (lower right).

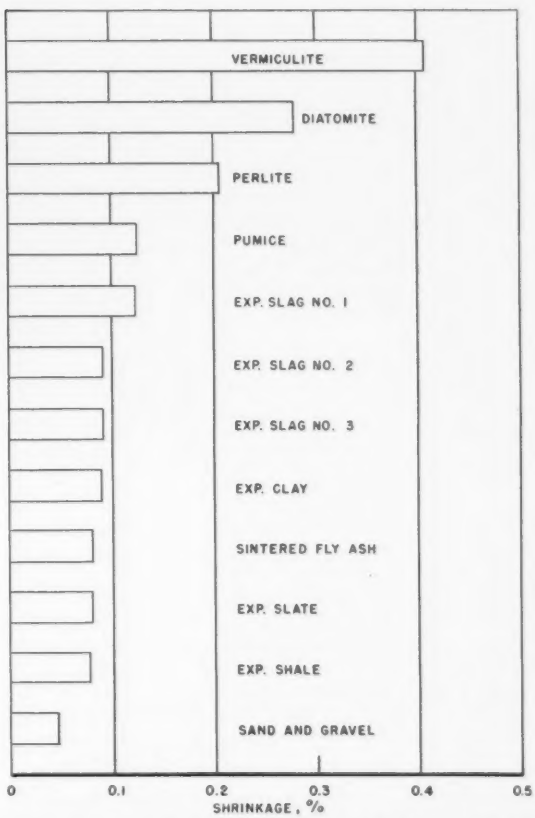


cessed lightweight aggregate materials have been studied in NBS and other using applications. Among the more significant and important properties ss after freezing and thawing cycles (lower left), compressive strength

crease in cement content. Use of air-entraining agents and increase in cement content improved durability of all concretes.

The coefficients of thermal conductivity (k values) range from 1.7 to 2.4 Btu/hr ft^2 (° F/inch) for the pumice concretes tested at the National Bureau of Standards as compared with values of 6.7 to 9.6 for sand and gravel concrete. Still lower k's (0.75 to 1.6) were measured on the vermiculite and perlite concretes. These two materials represent the extreme in light weight but have the consequent drawbacks of low strength and high porosity with related uncertainty of behavior under weathering unless protected. However, their low density and very low heat conductivity provide a great field of usefulness where strength is unimportant. The slags, expanded clay, shale and slate, sintered fly ash, and pumice are intermediate in their properties and can be used in place of conventional sand-and-gravel concrete except where extremely high strength is required. The lower thermal conductivity and lighter weight of these materials are advantages in practically all constructions.

The Bureau's investigations showed, in summary, that concretes, weighing as little as one-fifth the weight of ordinary concrete, are possible by using lightweight aggregates. Though these extreme lightweight concretes developed little strength, thermal conductivities as low as one-tenth that of sand-gravel concrete were exhibited. Other lightweight-aggregate concretes developed compressive strengths between 1,000 and 7,000 pounds per square inch, and weighed approximately one-third to two-thirds as much as sand-gravel concrete. Their thermal conductivities when dry were of the order of one-fourth to one-half those of the ordinary dense concrete. Most lightweight aggregates had relatively high water absorption, and shrinkage of the concretes made with them was approximately two or more times that of dense aggregate concrete. Except for lean 3-bag mixes, lightweight concrete containing air-entraining agents, in general, exhibited remarkable resistance to laboratory freezing and thawing tests of a rather severe nature.



Average drying shrinkage (100 days) of lightweight aggregate concretes.

Research Underlying a National Uniform Plumbing Code

Plumbing research at the National Bureau of Standards—directed at some of the most controversial plumbing problems—has provided certain comprehensive quantitative data required by code-writing authorities in preparing a proposed uniform plumbing code. This research program was undertaken by the Bureau at the request of the Housing and Home Finance Agency when it was fully realized that such a code might well play an important part in relieving a serious hindrance to the Nation's housing program resulting from the unrelated codes now in existence. Because existing data relating to the complicated flow characteristics in a drainage system are highly empirical, the Bureau's investigations were conducted in part with full-scale home plumbing systems of transparent plastic pipes, thereby permitting visual and motion-picture studies of the flow conditions. Working in close cooperation with this project are the code-writing authorities, which make up the Uniform Plumbing Code Committee. This group consists of representatives of the National Association of Master Plumbers, the United Association of Journeymen and Apprentices of the Plumbing and Pipe-Fitting Industry of the United States and Canada, the Housing and Home Finance Agency, the U. S. Public Health Service, and the National Bureau of Standards.

Today considerable confusion has resulted from the fact that each of more than 1,500 of the Nation's cities and towns has its own plumbing code, many of them differing, not only in details, but often in matters of major importance. Many of these codes are obsolete, contain many restrictive provisions, and do not embody improvements that have been made in plumbing in recent years. Often the provisions have no sound technical basis but are the result of more or less intelligent guesses that have become fixed over a period of years as a result of use.

Such a wasteful situation has imposed unnecessary expense on the public in many different ways. Designers and contractors must be familiar with the multitudinal details of the different codes in the various communities in which they operate. Materials that can be used in one city are prohibited in another. The interpretation of code requirements is often difficult, leading to time-consuming negotiations and sometimes the removal and replacement of construction partially completed. Manufacturers must furnish different variations of a given device or product to meet the varying requirements in different localities instead of standardizing their product. Unnecessarily large pipe sizes must be used, and vents that are not needed must be installed. This situation results in the useless expenditure of millions of dollars annually, to say nothing of the cost of unnecessary delays. The provision of adequate housing is thus retarded at a time when a serious housing shortage exists.

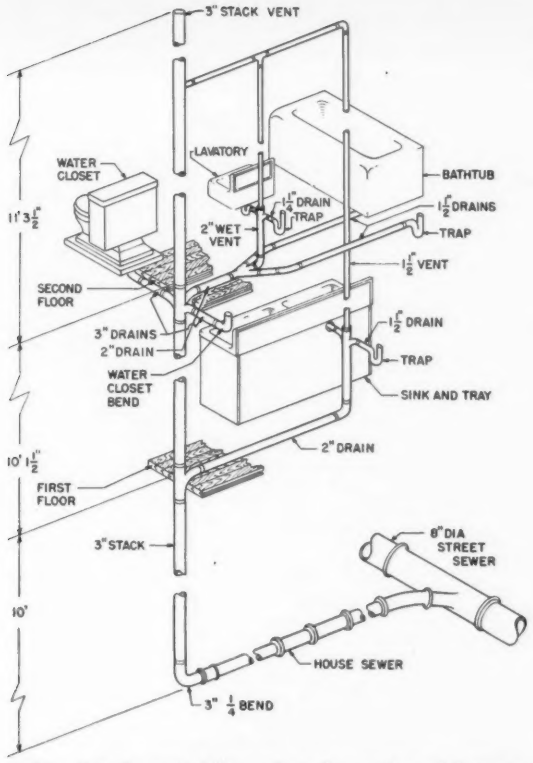
The seriousness of the situation has been recognized, as evidenced by the several plumbing codes proposed by interested organizations as national standards for adoption by municipalities throughout the Nation. Among these are the proposed codes of the National Association of Master Plumbers, the Western Plumbing Officials Code, and the American Standard Plumbing Code approved by the American Standards Association.

The Federal Government has also cooperated in the promotion of more adequate plumbing codes through the publication by the National Bureau of Standards in 1923 of Recommended Minimum Requirements for Plumbing, in Dwellings and Similar Buildings, followed in 1929 by a publication of similar title applying to all types of buildings, and more recently through the publication in 1940 of Building Materials and Structures Report BMS66, Plumbing Manual. The most recent effort of the Government to secure a general improvement in plumbing code requirements throughout this country was the establishment of the Uniform Plumbing Code Committee under the sponsorship of the Housing and Home Finance Agency, for the purpose of writing a proposed uniform plumbing code.

The serious lack of sound technical data on which to base some of the requirements of the code was appreciated from the beginning. One of the committee's first and most far-sighted acts was to take steps to remedy this deficiency in regard to certain portions of the code. With the support of the National Housing Agency (later of the Housing and Home Finance Agency), which financed the experimental work, arrangements were made with the National Bureau of Standards to conduct a comprehensive series of tests designed to throw light on certain matters involved in the code.

The factors that the Bureau was asked to investigate experimentally were (1) the self-siphonage of the traps used with such fixtures as lavatories, bathtubs, and

Plumbing systems, with pipes and fittings of transparent plastic, have been erected at the Bureau for studying technical problems involved in developing a Nationwide Uniform Plumbing Code.



sinks; (2) the suitability of stack venting of fixtures; and (3) the conditions under which wet venting of fixtures would be satisfactory. These were some of the most controversial subjects that would have to be considered in the writing of the code. The investigation centered on the siphonage of fixture traps in one- and two-story houses under different venting conditions; that is, the reduction of water seals in the fixture traps caused by pressure fluctuations in the building drainage system under various venting conditions.

In order to carry out this experimental investigation, three typical plumbing drainage systems were constructed in the Hydraulics Laboratory at the National Bureau of Standards. These systems were complete in every detail; each including a stack with horizontal branches or fixture drains, a building drain, and building sewer, and a street sewer. The street sewer was so arranged that flows up to 300 gallons per minute could be passed through it independently of flows from the stacks. Thus any desired degree of submergence of the house sewer could be simulated.

Recognizing the importance of being able to observe visually and photograph the complicated flow conditions, the systems were constructed entirely of transparent plastic pipe and fittings. Transparent methacrylate plastic pipe was available commercially in the desired sizes; stack fittings were manufactured of the same material with their internal dimensions accurately duplicating the dimensions of the commercial metal fittings.

Full-scale systems for two-story duplex houses exactly duplicated ordinary home plumbing except for the transparent plastic pipes and fittings. Complicated flow conditions could thus be observed visually and photographed.

Two single-story drainage systems were erected; the first of them representing a stack-vented system and the other a wet-vented system. In addition a two-story system was constructed corresponding to a duplex installation with bathrooms and kitchens back-to-back. In this installation the two groups of bathroom fixtures on the top floor were wet vented, and the two sinks on the first floor were back vented. The use of smooth plastic pipes, for the most part, made the test conditions more severe than would have been the case if the conventional metal pipes had been used. However, in order to assure that the test results would be directly applicable to service conditions, most of the tests were duplicated with metal traps, drains, and fittings in those portions of the systems in which the pipe material might in any way affect the results.

The investigation of fixture-trap self-siphonage involved the determination of the influence of such factors as the length, diameter, and slope of fixture drains, all of which may affect the seal loss in a trap when the fixture attached to the trap is discharged. For example, if the length of fixture drain between the trap and the point where a vent pipe to the atmosphere is connected to the drain is sufficiently great, an excessive reduction in the water seal of the trap will occur when the fixture is discharged. It is conceivable that under certain conditions the depth of water remaining in the trap will be so small that undesirable amounts of sewer gas would be admitted into the dwelling. For this reason, most plumbing codes place some restriction on the permissible distance between a fixture trap and its protecting vent. Basically, the problem of determining what this permissible length should be is simple, and it might have been expected that experimentation and experience would long since have determined this dimension. Nevertheless, such is not the case, and there is little or no uniformity among plumbing codes on this point.

The range in diversity of plumbing code requirements on this subject is well illustrated by the codes of two of the larger eastern cities. One requires that the unvented length of a fixture drain must not exceed 2 feet, whereas the other permits lengths of as much as 8 feet. The tests conducted at this Bureau under the sponsorship of the Housing and Home Finance Agency have shown why confusion on such a relatively simple problem could be possible. These investigations have demonstrated that the slope and diameter of the fixture drain, the various dimensions of the trap, the type of fitting joining the fixture drain to the vent, the rate of discharge from the fixture, and the shape and size of the fixture, as well as the distance between the trap and the vent fitting, all have an important effect on the observed trap-seal losses.

For example, nominal 1½-inch-diameter lavatory traps are not standardized. These traps may be made of drawn brass tubing with an internal diameter of 1⅜ inches, or they may be cast from brass or some other metal, in which case they may have an internal diameter

of 1½ inches or even as much as 1.61 inches. Tests have shown that traps with small internal diameters are more subject to seal losses from self-siphonage than traps having larger internal diameter. Hence a particular cast trap may not yield results even approximating those obtained with a tubing trap.

In like manner, lavatories, as well as other fixtures, are made in a variety of sizes and forms. Tests on the 18- by 20-inch lavatory have shown it to have, under certain conditions, less favorable self-siphonage characteristics, because of its smaller surface area, than the 20- by 24-inch lavatory. Again the Bureau investigations have revealed that the use of a short-turn drainage fitting at the end of the fixture drain where the vent connects to the system is in general preferable to the use of a long-pattern fitting. In addition, the rate of discharge from a fixture, which may be substantially affected by small changes in the size and shape of the outlet orifice, was found to exert an important effect on the results of the self-siphonage tests. This effect is sufficiently pronounced that it can sometimes be observed with fixtures of the same manufacture and model number, identical in every respect, except for small differences in the bevel provided on the outlet orifice to accommodate the rubber stopper.

Under these circumstances it obviously could not be expected that tests made in one city would yield results on the permissible unvented length of fixture drain that would be in any way comparable with test results obtained in another city, unless care were taken to insure that the traps, fixtures, vent fittings, and the other variables entering into the problem had been properly considered. Because of these facts, aside from their present use by code-writing authorities, it is possible that the data on self-siphonage will effectively aid in securing uniformity in the hydraulic characteristics of lavatories and fixture traps.

The investigation of the merits of stack venting of plumbing fixtures was made on a single-story system, complete with stack, building drain, building sewer, and street sewer. Fixtures are said to be stack-vented when they are grouped closely around the vertical stack with their drains connecting to the stack with no other venting. For a number of years stack venting has been advocated for a single-story system (or the top floor of any system) as offering adequate drainage and venting. At the same time it permits a reduction in cost as compared with the conventional back-vented system. This is possible because separate vent pipes to each individual fixture are not needed. Stack venting of fixtures has been one of the more controversial questions in the plumbing industry; it is permitted by many codes, whereas others prohibit it. The tests made at the Bureau have shown conclusively that under certain conditions stack venting of plumbing fixtures is a satisfactory method of venting.

The third problem investigated with reference to the proper venting of individual plumbing fixtures was the method commonly termed "wet venting". In this method of venting, a portion of the drain of one fixture serves as the vent of another fixture. Opponents of wet venting have claimed that a single pipe cannot adequately serve both as a vent and as a drain, and for this reason a large number of plumbing codes prohibit this type of venting. Nevertheless, in recent years there has been, because of the possible economy involved, a trend among code-writing authorities toward permitting the wet venting of plumbing fixtures under certain conditions. The specific problem given to the Bureau by the Uniform Plumbing Code Committee and the Housing and Home Finance Agency was to determine the factors affecting the performance of wet-vented traps in one- and two-story drainage systems and to determine under what conditions such venting would perform its function properly. The tests have shown that wet venting of one- and two-story drainage systems, with relatively simple restrictions on the fixtures involved and on the sizes of the wet vents, is entirely practicable and that under such circumstances advantage may be taken of the savings afforded by wet venting, as compared with back venting.

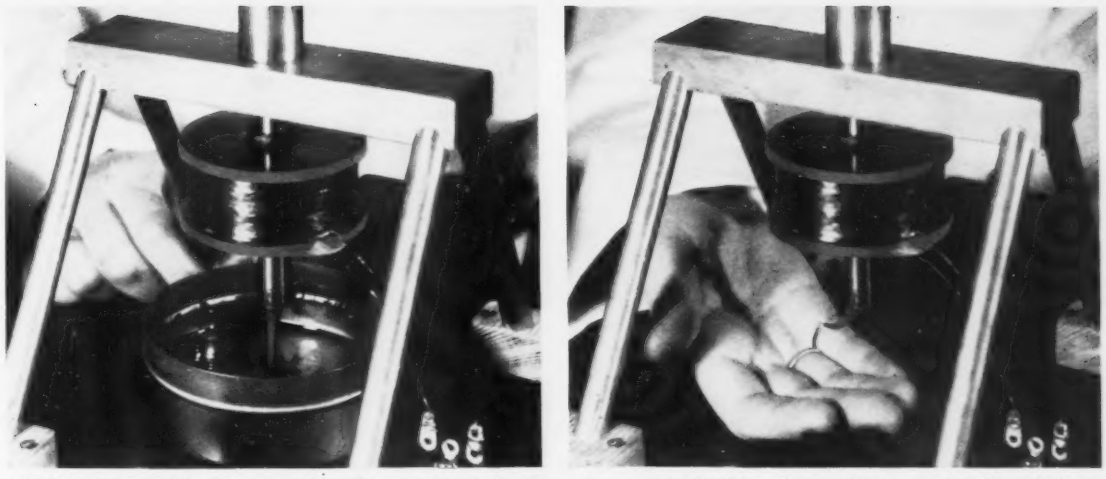
New Uses for Magnetic Fluids

The magnetic fluid originally used in the electromagnetic fluid clutch developed at the National Bureau of Standards has several unique features that make possible other important applications of iron-oil mixtures. Further studies of the properties of these mixtures have revealed that magnetic fluids can be employed to good advantage in hydraulic systems, shock absorbers, and dash pots; to form casting molds; and as variable electrical resistors. The basic property on which all these applications depend is that the viscosity of a magnetic fluid is directly related to the strength of the applied magnetic field—the fluid may be changed from a liquid to a nearly solid state and back again at will.

In some applications extreme fluidity is required at all times, whereas in others a thixotropic characteristic is needed. Thixotropic fluids are characterized by isothermal reversible gel-sol-gel transformations under shearing and subsequent resting. Mayonnaise, a good example of a thixotropic fluid, resists flow when its container is turned over, but may be stirred easily with a spoon. Honey, a nonthixotropic material, flows like all ordinary fluids but, because of its high viscosity, resists stirring.

When a magnetic fluid is used in a nonrotating device, the iron particles in the mixture must remain in suspension and not settle out. One way of achieving this is to use a thixotropic fluid. Another way is to maintain a small magnetic field in the mixture during idle periods. In rotating machinery, settling is less important as long as the iron powder can be readily remixed with the fluid. This can be achieved by adding a surface-active ingredient to the iron-oil mixture.

One engineering application proposed in the Bu-



A laboratory model of a magnetic valve to control the flow of magnetic fluid in a hydraulic system has been built at the National Bureau of Standards to test one of the many possible uses for the fluid originally used in the Bureau's magnetic fluid clutch. The magnetic valve is formed by winding a coil of wire around a pipe carrying magnetic fluid and then adjusting the electric current through the coil to control the rate of liquid flow. At left, the magnetic valve assembly is shown with zero current in the coil, resulting in full flow of the magnetic fluid; at right, the current is great enough to completely stop the flow. Other suggested applications of magnetic fluids include shock absorbers, dash pots, casting molds, and electrical resistors.

reau's preliminary investigation of new uses for magnetic fluids is the magnetic fluid dash pot. Basically, a dash pot consists of a piston moving in a fluid-filled cylinder with the viscosity of the fluid resisting the piston motion. In a conventional dash pot the rate of travel of the piston is determined by the external force, the fluid pressure on the piston, the dimensions of the fluid escape vent, and the fluid viscosity. Although the viscosity of the fluid depends to a large extent on its temperature, the speed of piston travel is not ordinarily regulated by controlling temperature. The only variable usually controlled is the pressure on the piston. The rate of piston travel can be adjusted mechanically by providing a variable orifice in the piston or in the cylinder wall—a method that presents a number of complications.

On the other hand, if a magnetic fluid is used in the dash pot the rate of motion of the plunger can be readily controlled by magnetically varying the viscosity of the fluid. If a coil of wire is placed around the dash pot, the viscosity of the magnetic fluid will be a function of the current in the coil. Employing this idea in the design of shock absorbers for automobiles and trucks would provide an adjustable riding quality to meet various loading and roadway conditions. The rate of response of the magnetic fluid is high enough to provide virtually instantaneous changes in viscosity, thereby making possible a shock absorber with automatic compensation.

The electromagnetically controllable fluid offers interesting possibilities for use in hydraulic systems. If a hydraulic system is filled with a magnetic fluid, valving becomes extremely simple: By winding a coil of wire around a fluid-carrying pipe and controlling the amount of current through the coil, the flow of fluid past that point can be closely regulated from full flow to complete cut-off. An obvious advantage of this scheme is that various points in a hydraulic system can be remotely controlled from a central station.

Electromagnetic fluids are also being investigated for use in molding operations. A fluid is placed in a pot surrounded by a current-carrying coil, a model of the part to be cast is placed in the fluid, and the coil is then energized so that the fluid will solidify around the model. When the model is removed, a detailed impression remains outlined in the solidified magnetic fluid. Molding compound can then be poured into the mold and allowed to harden. After the coil current is turned off the molded replica can easily be removed from the liquid. In any application of this kind, the boiling point of the magnetic fluid must of course be higher than the temperature of the molten casting material.

An electrical resistor adapted to remote control can be made by immersing two electrodes in a magnetic fluid. When the fluid is in an unmagnetized condition, the resistance between the two electrodes will be extremely high because of the very loose contact among the conductive iron particles that are randomly distributed in the nonconductive oil. In the presence of a magnetic field, however, the iron particles apparently form chains along the lines of magnetic flux and draw into close physical contact. The flux density will determine the massiveness of the chain and, thus, the conductivity of the mixture. When the system is de-energized, the conductance does not drop back to its former very low level. This property of magnetic fluid resistors is attributed to the coherer effect that has been previously investigated by Branley, Marconi, and others.

The success or failure of any device utilizing magnetic fluid will depend to a considerable extent on the particular components in the iron-oil mixture, the choice of suspension fluid and iron powder in large measure being determined by the application for which the mixture is intended. The iron powder is one component of the mixture not generally varied from one application to another, since certain properties are considered essential for satisfactory operation: In order to achieve maximum magnetic efficiency, the iron powder must have high permeability; to minimize wear and abrasion on moving parts the particles should have smooth, continuous exteriors; and the iron powder must be chemically stable, resisting oxidation in the suspension fluid.

In mixtures where it is essential to prevent settling and sedimentation, the particles should be of uniform size and no larger than about 20 microns in diameter. A great many powders have been tried at the Bureau, including pure iron, alloys, oxides, and ferrites. The powder that has proved most universally successful is a carbonyl iron in the form of particles about 8 microns in diameter.

The choice of a suspension fluid is not so simple. Some of the factors that must be considered are chemical stability, flammability, vapor pressure, and viscosity. In any magnetic fluid device where there is considerable mechanical movement, the viscosity of the suspension fluid may be especially important, and if it is desirable to hold the viscous drag at a low value during nonenergized periods, a low-viscosity fluid must be used. The fluids must also be chemically stable in the presence of the iron powder and should not become sticky or gummy at high temperatures.

In earlier experiments at the Bureau, it was found that many ordinary lubricating oils have enough sulfur in them to cause rapid oxidation and clumping of the iron particles. It was also found that many animal oils (including lard or sperm) tend to catalyze and become gummy and solid. One type of fluid that is remarkably stable in the presence of iron powder is a silicone liquid that has a viscosity of around 50 centistokes at 25° C. It is excellent with respect to nonflammability and vapor pressure, and this versatile fluid will serve satisfactorily in nearly all but extremely high-temperature applications. When it is necessary to operate a magnetic fluid device at elevated temperatures, special compounds, such as fluorinated and chlorinated fluids can be used, but special precautions must be taken with the seals, since the vapors from these fluids are quite toxic.

NBS Publications

Periodicals [5]

Journal of Research of the National Bureau of Standards, volume **42,** number 5, May 1949. (RP1982 to RP1990, inclusive.)

Technical News Bulletin, volume **33,** number 5, May 1949. 10 cents.

CRPL–D57. Basic Radio Propagation Predictions for August 1949. Three months in advance. Issued May 1949. 10 cents.

Nonperiodical [5]

Research Papers [5 6]

RP1972 Characterization of some commercial soaps by X-ray diffraction. Gopal S. Hattiangdi. 10 cents.

RP1973 Characterization of alkali soaps by electron microscopy. Gopal S. Hattiangdi and Max Swerdlow. 15 cents.

RP1974 Some physical-chemical properties of aqueous solutions of soaps and soapless detergents. Gopal S. Hattiangdi, William W. Walton, and James I. Hoffman. 10 cents.

RP1975 Doubly charged ion spectra in mass spectra of hydrocarbons. Fred L. Mohler, Evelyn G. Bloom, Edmund J. Wells, Jr., Jonathan H. Lengel, and C. Edward Wise. 10 cents.

RP1976 Heats, equilibrium constants, and free energies of formation of cyclopentene and cyclohexene. Morton B. Epstein, Kenneth S. Pitzer, and Frederick D. Rossini. 10 cents.

RP1977 The preparation of calcium melibionate. William W. Walton and Horace S. Isbel. 10 cents.

RP1978 Polarographic limiting currents. John Keenan Taylor, Roberta E. Smith, and Irvin L. Cooter. 10 cents.

RP1979 Stress distribution near reinforced circular hole loaded by pin. Samuel Levy and Frank C. Smith. 10 cents.

RP1980 The volumetric determination of columbium. Howard B. Knowles and G. E. F. Lundell. 10 cents.

RP1981 Effect of concentration on the viscosity of dilute solutions. Robert Simha. 10 cents.

Commercial Standards [5]

CS56–49 Oak flooring. (Third edition. Supersedes CS56–41.) 10 cents.

Handbooks [5]

H41 Medical X-ray protection up to two million volts. (Supersedes H20.) 15 cents.

Simplified Practice Recommendations [5]

R26–49 Steel reinforcing bars. (Supersedes R26–42.) 10 cents.

R29–49 Eaves trough, conductor pipe, and fittings. (Supersedes R29–42.) 10 cents.

R217–49 Copper water tube and copper and brass pipe. (Supersedes R217–46.) 10 cents.

Articles by Bureau Staff Members in Outside Publications [7]

Primary instability of open-section stringers attached to sheet. Wilhelmina D. Kroll. J. Aeronautical Sci. (2 East 64th St., New York 21, N. Y.) **15,** 581 (1948).

Exposure meter for precision light-dosage. Herbert F. Launer. Rev. Sci. Inst. (57 East Fifty-fifth St., New York 22, N. Y.) **20,** 103 (1949).

Photochemistry of Cellulose. Effects of water vapor and oxygen in the far and near ultraviolet regions. Herbert F. Launer and William K. Wilson, J. Am. Chem. Soc. (1155 Sixteenth St., N. W. Washington 5, D. C.) **71,** 958 (1949).

[5] Send orders for publications under this heading only to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Annual subscription rates: Journal of Research, $4.50 (foreign $5.50); Technical News Bulletin, $1.00 (foreign $1.35); Basic Radio Propagation Predictions, $1.00 (foreign $1.25). Single copy prices of publications are indicated in the lists.

[6] Reprints from April Journal of Research.

[7] These publications are not available from the Government. Requests should be sent direct to the publishers.

U. S. GOVERNMENT PRINTING OFFICE: 1949